Pretreatment Spinal Column Dose Estimation for Spinal SBRT Using Octavius Four-dimensional Phantom and Dose-volume Histograms Four-dimensional Feature: A Dosimetric Analysis

Mallikarjuna Adavala[1,2], Chandrasekhar Reddy K[3], Shakambari Sadangi[2], Kausik Bhattacharya[2]

[1]Department of Physics, Rayalaseema University, Kurnool, [3]Department of Physics, Government Degree College, Uravakonda, Andhra Pradesh, [2]Department of Radiation Oncology, AIG Hospitals, Hyderabad, Telangana, India

Abstract

Aim: The aim of this study was to estimate the spinal column dose for spinal Stereotactic body radiation therapy (SBRT) before patient treatment using the PTW dosimetry Octavius dose-volume histograms (DVH) four-dimensional (4D) feature. **Materials and Methods:** Twenty-three patients were included in the study, and a volumetric modulated arc therapy plan with 6MV flattening filter-free (6FFF) was generated for each patient in the Eclipse planning system using the Anisotropic Analytical Algorithm (AAA) algorithm (Varian Medical Systems, Palo Alto, CA) for the TrueBeam STx LINAC machine. The Octavius 4D system was used to estimate the spinal cord dose by delivering the plans to the 4D phantom. The measured dose was compared with the Eclipse treatment planning system (TPS) (Varian Medical Systems, Palo Alto, CA) dose. **Results:** The spinal cord max and mean doses estimated using Varisoft DVH 4D are in close agreement with the TPS calculated max and mean doses. The deviation between measured dose and TPS dose is ±5% for the spinal max dose, and the deviation between measured dose and TPS dose is ± 3% for the spinal mean dose. **Conclusions:** The study demonstrates that the PTW Octavius 4D phantom and DVH 4D feature can be used as a tool to estimate spinal cord dose before the treatment in spinal SBRT plans. The system provides an independent dose measurement that is comparable to the TPS dose. The close agreement between measured and calculated doses validates the use of this system as a critical organ dose verification tool.

Keywords: Dose-volume histograms four-dimensional, Eclipse treatment planning system, SBRT, volumetric modulated arc therapy

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Introduction

This study was undertaken with the primary aim of assessing the utility of the four-dimensional (4D) Octavius System in estimating doses to organs at risk (OAR) in the context of radiotherapy treatments for various patients. The core objective was to investigate whether the 4D Octavius System, known for its capacity to provide dynamic and real-time dosimetry data, could offer a reliable and effective means of estimating OAR doses during radiation therapy. Spinal metastasis is the third-most common type of metastasis after lung and liver. Along with surgical procedures for spine metastasis, complications occur in both the perioperative and postoperative periods.[1,2] Radiation therapy for patients with spinal metastasis helps in effective pain management.[3] With the help of advanced technology and computerized planning, the dose can be delivered more accurately and precisely. Conventional treatment for spinal metastasis involves 20 Gy in five fractions, with a response of 10%–20%. However, delivering a high dose for spinal metastasis has been found to be more effective with a dose regimen of 27 Gy in three fractions.

In the past few decades, stereotactic body radiotherapy has shown better results in pain management in spinal metastasis than conventional radiotherapy.[4] With advanced radiotherapy technologies, it is feasible to delineate the target and deliver a biologically high dose to the target while sparing normal

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Address for correspondence: Mr. Mallikarjuna Adavala, Department of Radiation Oncology, AIG Hospitals, Gachibowli, Hyderabad - 500 032, Telangana, India. E-mail: amallikarjuna@gmail.com

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tissue simultaneously, with the help of rigid immobilization devices, computerized planning systems, high-end diagnostic modalities, and image-guided radiotherapy. Pretreatment patient-specific QA and estimating dose to critical organs give confidence about treatment delivery.

The purpose of this study is to estimate the spine dose using 4D Octavius phantom and dose-volume histograms (DVH) 4D before treatment in spine Mets SBRT. This stereotactic body radiotherapy technique involves a high dose per fraction results in high biological dose to target, a steep dose gradient to reduce the spine dose, and complex MLC segments, making it essential to focus on the spine dose.[5]

For the treatment plan, 6 × FFF energy is used which helps to reduce head scatter, treatment delivery time, and dose outside the field. The desired dose distribution for spinal ablative radiotherapy is well type, and to ensure that patient-specific QA is highly essential.[6]

Materials and Methods

The study's description of its materials and methods is presented as follows. The dose prescribed by the radiation oncologist for patients was 27 Gy in three fractions and dose received by 0.1 cc of the spinal column considered as max dose.[7] As shown in Figure 1 volumetric-modulated arc therapy plans were generated using 6FFF energy and AAA algorithm[8] with control point spacing <3° for a TrueBeam STx linear accelerator in the Eclipse 15.6 planning system (Varian Medical Systems, Palo Alto, CA).

A pretreatment QA protocol was followed using the Octavius 4D[9] cylindrical phantom and a verification plan was created in the PTW system. The dose was calculated for the phantom, and the QA plan and dose were exported to the PTW system for irradiation. The dose was measured using the Octavius 4D system, which is comprised of a two-dimensional (2D) detector array and a detector interface for data acquisition.

The Octavius 4D phantom is a motorized, modular phantom consisting of a rotation unit with four exchangeable tops. The rotation unit has a diameter of 320 mm and a length of 343 mm, and it is made of polystyrene with a density of 1.05 g/cm^3.[10] It can rotate ±360°, and its rotational speed is max 28°/s. Its position reproducibility is ±1°.

The Octavius 4D system uses 1405 vented parallel plate-type ionization chambers arranged in a chessboard matrix pattern, providing a maximum 27 cm × 27 cm field + coverage. The phantom is designed with a wireless inclinometer that generates real-time information about the current beam angle. With the angle information, the control unit is able to rotate the rotation unit so that the beam incidence is always perpendicular to the 2D array.

As shown in Figure 2 the PTW Octavius phantom was commissioned and validated for TrueBeam STx and Eclipse treatment planning system (TPS) (Varian Medical Systems, Palo Alto, CA), and the synchrony of the rotation of the LINAC gantry and Octavius 4D was verified at different speeds of the gantry.[11] Cross-calibration for temperature and pressure was performed for the vented type parallel plate ionization chamber, followed by measurement and gamma analysis with 3% and 3 mm distance-to-agreement (DTA).[12]

For the evaluation of dose to individual organs, the DVH 4D software was used to compare DVHs. The software was developed based on the interdependence between the percentage dose difference (%DD)[13] and the gamma pass rate and an accuracy analysis of the software was performed. The correlation coefficient was used to establish the grade

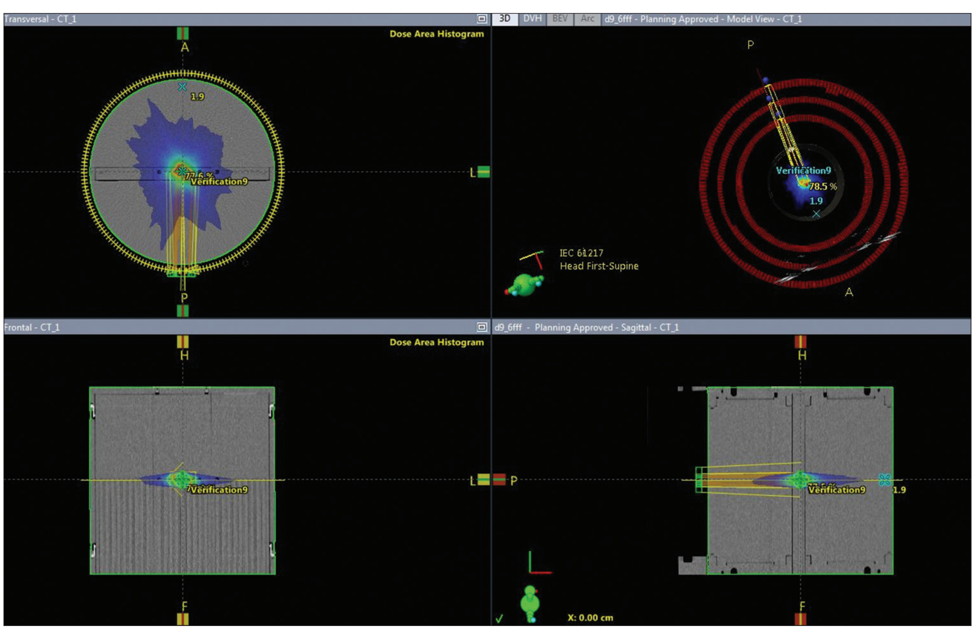

Figure 1: QA plan with beams

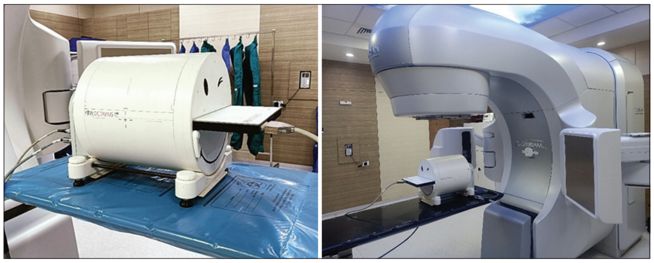

Figure 2: PTW Octavius four-dimensional phantom, TrueBeam STx LINAC

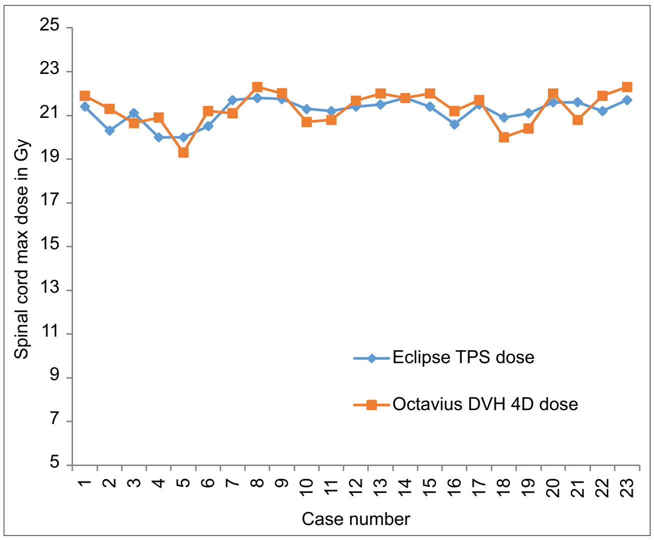

Figure 4: Comparison of spinal cord max dose. TPS: Treatment planning system, DVH: Dose-volume histogram, 4D: Four dimensional

of correlation, and their results showed a weak-to-moderate correlation for all structures. The three-dimensional gamma pass rate using the DVH 4D software was found to be above 95% for all the cases. The 3DVH prediction of the spinal column dose was calculated using computed tomography (CT) images and exported to the PTW dosimetry system.

Unlike other QA devices, DVH 4D algorithms are completely independent of dose information calculated by TPS. Calculate structure's DVH entirely based on Octavius 4D measurement data and the patient's anatomy, using density values from the patient's CT scan. The Octavius 4D algorithm is based on dose measurements at a certain depth in the phantom and on percentage depth dose curves (PDDs) that are used to reconstruct dose values along the ray lines that connect the relevant detectors and the focus of the beam. The commissioning of Octavius 4D is limited to PDD measurements and the measuring results. The phantom is cylindrical, and the detector array is inserted at the center of the phantom, which is at a depth of 15 cm from the cylindrical surface. The phantom with detector array is rotating with the gantry, ensuring that the source-to-surface distance of 85 cm is always maintained.

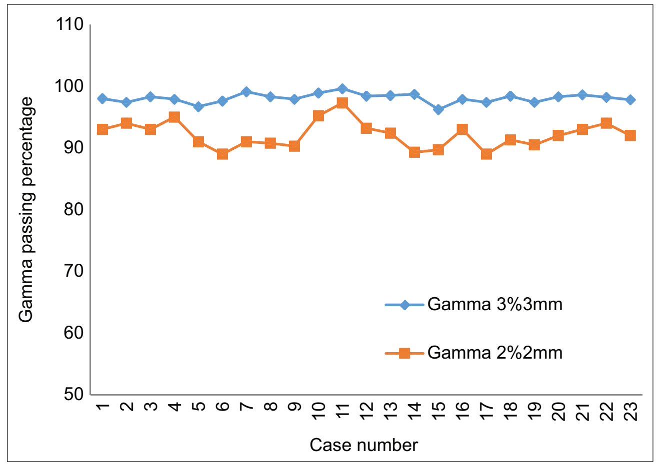

Figure 3: Gamma analysis 3% 3 mm and 2% 2 mm

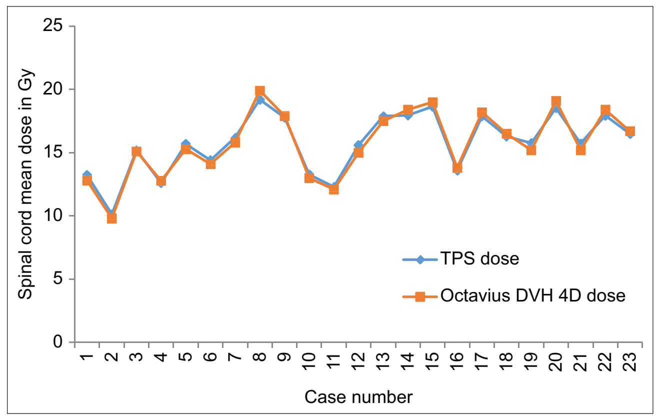

Figure 5: Comparison of spinal cord mean dose. TPS: Treatment planning system, DVH: Dose-volume histogram, 4D: Four dimensional

Results

Gamma analyses

The given data represent the results of two gamma analyses one with a 3% DD and 3 mm DTA criteria and the other with a 2% DD and 2 mm DTA criteria performed on 23 patient cases.[14]

The gamma analysis is a widely used tool to evaluate the agreement between the measured and calculated dose distributions. It calculates the percentage of points in the measurement that pass a set of criteria for the DD and DTA. In general, a gamma pass rate of >95% is considered acceptable for patient-specific QA.

In the current dataset as shown in Figure 3, we can see that the gamma pass rates for both criteria are generally high, indicating good agreement between the measured and calculated dose distributions. The mean gamma pass rate for 3% DD and 3 mm DTA criteria is 98.07% (range: 96.2%–99.6%), and for 2% DD and 2 mm DTA criteria, it is 92.13% (range: 89%–97.3%).

It is important to note that the gamma pass rate is dependent on various factors such as the complexity of the treatment plan, measurement system, and the gamma criteria used. Hence, it is recommended to establish institution-specific criteria based on clinical experience and guidance from professional organizations.

Overall, the results of the gamma analysis presented in this dataset indicate good agreement between the measured and calculated dose distributions and suggest that the patient-specific QA process is effective in ensuring the accuracy of the treatment plan delivery.

Table 1 compares the maximum and mean spinal cord dose for spine stereotactic body radiotherapy (SBRT) using two different systems Eclipse TPS (Varian Medical Systems, Palo Alto, CA) and Octavius DVH 4D. The data include 23 cases and provide the maximum and mean dose for each case as well as the percentage deviation between the two systems.

The mean percentage deviation for the maximum dose is 2.66% with a standard deviation of 1.18%, indicating that the Eclipse TPS (Varian Medical Systems, Palo Alto, CA) generally delivers slightly lower maximum spinal cord doses compared to the Octavius DVH 4D. The mean percentage deviation for the mean dose is 2.31% with a standard deviation of 0.94%, suggesting that there is not much difference between the two systems in terms of mean spinal cord dose.

Overall, the differences in spinal cord dose between the two systems are small, with both systems generally delivering safe doses that are well below the tolerance limits for spinal cord dose. However, it is important to note that every case is unique and may have specific requirements that need to be considered while selecting the TPS.

In conclusion, the data show that there is not much difference between the two systems in terms of mean spinal cord dose, but the Eclipse TPS (Varian Medical Systems, Palo Alto, CA) delivers slightly lower maximum spinal cord doses compared to the Octavius DVH 4D. The small differences between the two systems suggest that both systems can be used for spine SBRT with confidence, but individual case requirements should be considered when selecting the TPS.

Discussion

Tables 1 and 2 represent a comparison of maximum and mean spinal cord doses for spine SBRT using the TPS and treatment verification system: Eclipse TPS (Varian Medical Systems, Palo Alto, CA) and Varisoft DVH 4D. Table 1 includes 23 patients, and for each patient, the maximum and mean spinal cord doses were calculated using Eclipse15.6 (Varian Medical Systems, Palo Alto, CA) and verified by PTW Verisoft DVH4D. From Figures 4 and 5 the result shows the percentage deviation between the maximum and mean doses obtained from the TPS and treatment verification system.

Table 1: Comparison of spinal cord dose for spine stereotactic body radiotherapy

Case number	Eclipse TPS		Varisoft DVH 4D		Deviation	
	Maximum dose (Gy)	Mean dose (Gy)	Maximum dose (Gy)	Mean dose (Gy)	Maximum dose deviation (%)	Mean dose deviation (%)
1	21.4	13.24	21.9	12.8	2.34	3.32
2	20.3	10.14	21.3	9.8	4.93	3.35
3	21.1	15.2	20.65	15.1	2.13	0.66
4	20	12.6	20.9	12.78	4.50	1.43
5	20	15.7	19.3	15.28	3.50	2.68
6	20.5	14.4	21.2	14.1	3.41	2.08
7	21.7	16.2	21.1	15.8	2.76	2.47
8	21.8	19.2	22.3	19.9	2.29	3.65
9	21.75	17.78	22.01	17.9	1.20	0.67
10	21.3	13.27	20.7	12.98	2.82	2.19
11	21.2	12.3	20.8	12.1	1.89	1.63
12	21.4	15.599	21.67	15	1.26	3.84
13	21.5	17.887	22	17.5	2.33	2.16
14	21.8	17.953	21.8	18.4	0.00	2.49
15	21.4	18.641	22	19	2.80	1.93
16	20.6	13.591	21.2	13.8	2.91	1.54
17	21.5	17.87	21.7	18.2	0.93	1.85
18	20.9	16.276	20	16.5	4.31	1.38
19	21.1	15.765	20.4	15.2	3.32	3.58
20	21.6	18.522	22	19.1	1.85	3.12
21	21.6	15.725	20.8	15.2	3.70	3.34
22	21.2	17.935	21.9	18.4	3.30	2.59
23	21.7	16.494	22.3	16.7	2.76	1.25
Mean±SD					2.66±1.18	2.31±0.94

SD: Standard deviation, TPS: Treatment planning system, DVH: Dose-volume histogram, 4D: Four dimensional

Table 2: Gamma analysis

Case number	Gamma 3%, 3 mm	Gamma 2%, 2 mm
1	98	93
2	97.4	94
3	98.3	93
4	97.9	95
5	96.7	91
6	97.6	89
7	99.1	91
8	98.3	90.76
9	97.9	90.3
10	98.9	95.2
11	99.6	97.3
12	98.4	93.2
13	98.5	92.4
14	98.7	89.3
15	96.2	89.7
16	97.9	93
17	97.4	89
18	98.4	91.3
19	97.4	90.5
20	98.3	92
21	98.6	93
22	98.2	94
23	97.8	92
Mean±SD	98.07±0.75	92.13±2.14

SD: Standard deviation

There are several potential reasons for the observed differences in spinal cord doses between Eclipse (Varian Medical Systems, Palo Alto, CA) and PTW Varisoft DVH4D. One reason could be differences in the algorithms used for dose calculation. Another reason could be differences in the underlying models used for calculating the dose to the spinal cord. In addition, differences in the beam modeling and optimization algorithms used in the two systems could also contribute to the observed differences.

Overall, the presented data highlight the importance of carefully evaluating the dose calculation algorithms and models used in TPS s for SBRT treatments. The differences in the calculated spinal cord doses between Eclipse (Varian Medical Systems, Palo Alto, CA) and Varisoft DVH4D could potentially impact the risk of radiation-induced toxicity and should be carefully considered when designing and delivering SBRT treatments. Further research and investigation are necessary to understand the underlying causes of these differences and to optimize treatment planning strategies for spine SBRT.

Conclusions

The study compares the spinal cord dose for spine stereotactic body radiation therapy (SBRT) using estimated dose with Octavius 4D Varisoft DVH 4D with Eclipse TPS (Varian Medical Systems, Palo Alto, CA) calculated planned dose. The results show that the average deviations in maximum and mean doses to the spinal cord are 2.66% and 2.31%, respectively, compared to Eclipse TPS dose and the standard deviations of maximum and mean dose to the spinal cord are 1.18% and 0.94%, respectively, with respect to Eclipse TPS dose.

In conclusion, the study suggests that the pretreatment verification using Varisoft DVH 4D offers improved confidence in treatment dose delivery. The size of the tumor varying from 4.9cc to 36.9cc and the field size used ranging from 4 cm × 2 cm to 8 cm × 8 cm.

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Conflicts of interest

There are no conflicts of interest.

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